# SXI-M RECALIBRATION ANALYSIS
## EXECUTIVE SUMMARY

## 1. Purpose

Recalibration of the SXI-M optical system at the MSFC X-Ray Calibration Facility (XRCF) was undertaken in February 1998 to resolve two key issues that resulted from analysis of the February 1997 calibration tests in the Stray Light Facility (SLF):

- The throughput sensitivity of the full SXI optical system seemed to below par by a factor of roughly 5–6, relative to the values expected from theoretical predictions and component tests. The same deficit was measured at both short (8.3Å, Al source) and long (44.7Å, C source) wavelengths. No convincing physical explanation for the deficits was apparent to the analysis teams, and it was concluded that shortcomings in the SLF itself at least contributed to the problem.
- It was recognized that insufficient images had been taken in the SLF tests to permit determination of the system point-spread-function with the accuracy needed for the development of image restoration algorithms for operational purposes. This would be especially critical around the maximum phase of the solar cycle, when it is certain that bright flares will frequently saturate the system and fog the images.

Recalibration of the instrument in a more stable facility would also provide an opportunity to obtain supplemental imagery for characterizing additional aspects of system performance.

## 2. Analyses

The recalibration analysis consists of four separate documents:

[1] "GOES-M Solar X-ray Imager (SXI) Recalibration Report," G. D. Berthiaume, MIT/Lincoln Labs Project Report NOAA-23, 31 July 1998. Includes analyses of absolute calibration data, background corrections, system sensitivity (effective area), encircled energy, focus, filters, and blooming effects. Uses direct counting methods to determine net signal in an image.

[2] "SXI Recalibration Report: Effective Area Measurements," J. M. Davis, MSFC memo ES82(98-064), July 14, 1998. Report on SXI system sensitivity, using direct counting methods.

[3] "SXI Recalibration Analysis Report," M. Adams, MSFC, December 16, 1998. **[contents TBD].**

[4] "SXI Recalibration Analysis Report: Point-Spread Function," V. J. Pizzo, NOAA/SEC, 17 December 1998. Includes analyses of backgrounds, point-spread function (PSF), system sensitivity (effective area), encircled energy, focus, filters, and resolution. Contains full description of "halo" properties. Uses integration of PSF fit to determine net signal in an image.

## 3. Findings

Discussion of specific findings in these documents will be identified in the following by the above numeral designation. For example, "([4], S6.3)" refers to Section 6.3 in the document labeled "[4]" above.

### 3.1 Backgrounds

The background (no source) signal on the SXI detector consists mainly of offset bias voltage and thermal noise components, which need to be subtracted from each image before further processing. The background is neither smooth nor flat, and it varies with exposure time. Moreover, because each line in the CCD is normalized to a shielded reference pixel, the noise varies line-by-line in each image. A variety of methods were developed for subtracting the background from each image (e.g., [1], S2.2, S5; [2], S4; [4], S5–6), but the upshot is that the choice of method does not influence any basic result and at worst only amplifies somewhat the error and uncertainty in the details.

### 3.2 Point Spread Function

The PSF results are considered first, because of the key finding that a faint diffuse ring or "halo" of unknown physical origin surrounds each point image for a very great distance ([4], Fig. 19). It was expected that the PSF of the SXI instrument should be described by a "Moffit" function, which is essentially a modified Lorentzian profile (Gaussian core, power-law wings) accounting for the wide-angle scattering commonly found in X-ray grazing-incidence systems. The extended halo prompted the adoption of an adhoc piecewise-continuous fit to the PSF, consisting of a Moffit inner part and a pure power-law outer part ([4], S6.3).

The primary PSF series, in which 80–90 point images were taken at each of several field angles for Al and C sources, yield well-defined values for the fit parameters at 873V on the MCP (see [4], Tables 2–4). Information on the MCP voltage dependence of the PSF is derived from a sequence of images taken at the C wavelength ([4], Table 5). These values will provide the basis for operational algorithms for post-processing the images to reduce fogging and sharpen solar features.

Although there is currently no physical explanation for the origin of the halo, this PSF analysis provides ample characterization of halo properties ([4], S9). In brief,

- The halo is visible in raw, deeply exposed images, is not an artifact of the analysis
- The halo is diffuse, is not composed of photons scattered by the mirror
- It has distinct inner and outer boundaries
- The fraction of total signal in the halo is 37% at Al, 25% at C wavelength
- The signal in the halo is large enough to affect measures of other SXI optical properties, such as sensitivity and encircled energy
- This wavelength dependence may stem from differences in the point-image profile input to the detector by the mirror optics
- Halo properties do not appear to depend upon MCP voltage or field angle

### 3.3 Sensitivity (Effective Area)

The sensitivity of the SXI system is measured by comparing the total signal in a point image with that predicted from measured component transmission values, given a test source of known intensity. The test source is the X-ray flux passing through a tiny pinhole at the XRCF, which produces a uniform beam at the SXI. The intensity of the beam is monitored by facility counters and was found to be very stable and well-determined ([1], S2.1; [2], S1–3).

For simplicity, SXI sensitivity is expressed in terms of the mirror effective area ([1], Eqn. 1). The net signal collected at the detector was determined by subtracting the background and counting all the remaining DN within a box surrounding the point image ([1], S2.4–5; [2], S4–5). The results of the effective area calculation are summarized below.

SXI Effective Areas

| Wavelength (Å) | Area[1] cm$^2$ | Area[2] cm$^2$ | Predicted Henke | Predicted Ershov |
|---|---|---|---|---|
| 8.33 | 0.22 | 0.21 | 1.33 | 0.59 |
| 9.89 | 0.33 | 0.44 | 1.43 | 1.09 |
| 13.3 | 0.52 | 0.68 | 0.98 | 0.97 |
| 44.7 | 5.98 | 4.80 | 5.15 | 6.16 |

Error bars for the measured areas are provided in [1], but the uncertainties in the predicted values have not been established. Certainly, those should be substantial at short wavelengths, where both detector and mirror responses vary rapidly with wavelength. It is also noted that the error at the intermediate wavelengths in the above table cannot be firmly determined, since the detector response was never measured directly.

It was demonstrated ([4], S11) that these measures are consistent with each other and the PSF analysis, when allowance is made for differing counting box sizes. It was also shown that effective area estimates from direct counting should be increased by factors of 1.54 at Al and 1.28 at C to account properly for the halo. This would elevate the Al estimate to a value of 0.34 cm$^2$.

We conclude that the SXI long-wavelength sensitivity is well within expectations, but the Al sensitivity still falls short of the prediction by a factor of 2–3. But given the uncertainties in the predictions, it difficult to assess the true magnitude of the short-wavelength deficit.

### 3.4 Encircled Energy

The specifications requirements for SXI state that at the C wavelength, 25% of the energy in a point image shall lie in a single pixel and 40% shall be contained in a 2×2 pixel square. Both focus map analyses ([1], S4; [4], S12) and the direct PSF analysis ([4], Figures 10 and 24–26) indicate the instrument fails to meet this requirement by a substantial margin.

### 3.5 Focus

Direct counting and PSF assessments of the variation in focus with field angle ([1], S4; [4], S12) concur that a flat, if soft, focus has been achieved in the center of the CCD across a region the size of the solar disk.

### 3.6 Resolution

The PSF analysis indicates the SXI system is close to meeting the specifications requirement that two 8.3Å point images lying 15 arcmin off-axis and separated by 15 arcsec should be resolved ([4], S14).

### 3.6 Filters

Recalibration testing provided an opportunity to verify SXI filter transmissions. The ratio between DN collected in images with each filter in place and the DN in images with no filter is compared with filter transmissions computed from measured properties of the filters ([1], S2.3; [4], S13). Given the error estimates for the collected DN and allowing for the likely uncertainties in the measured thicknesses of the filters (not available), it appears the only filter showing a substantial discepancy is the thin Beryllium filter in hardware position #5, which tests out 15–20% low in transmission.

### 3.7 Saturation/Blooming

The XRCF tests ([1], S3) indicate a weak tendency for the detector to saturate at high flux levels (i.e., some DN is lost, relative to linear expectation in series of increasing exposures). Due to limitations in the XRCF source strength, saturation was achieved by lengthy integration time, so some uncertainty remains concerning the detector saturation response to intense fluxes sustained over the short integration times (3 sec or less) typical of operations.

## 4. Unresolved Issues

The recalibration analysis was not intended to cover every aspect of instrument performance, but rather to provide resolution to the sensitivity question and to afford sufficient PSF information to support operational image processing needs. The image and analysis data and the analysis software remain online at NOAA/SEC and MSFC, to be utilized to address further specific questions as they arise.

Two outstanding issues are:

- The physical origin of the halo. The halo properties, in particular its diffuse nature and sharp boundaries, suggest that it arises from some additional scattering process in the detector.

- Convolution of detector with mirror PSF. The full system PSF tests out sharper than the measured detector PSF (K. Russell and J. Chappell, "Spatial Characterization of the SXI Flight Detector," NEARL Report, May 22, 1996), which raises a physical contradiction. Ideally, convolution of the SLF mirror slit-scan results with the detector response should be proven consistent with the XRCF tests analyses.